

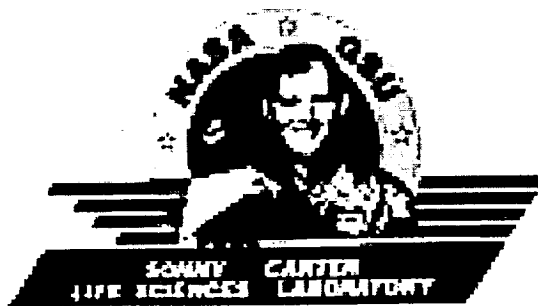
Behavior & Performance Project

(Bion-11 Experiment B11-16)

Final Report

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SUPPORTED BY NASA GRANT NAG2-438 TO GEORGIA STATE UNIVERSITY



April, 1998

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Behavior & Performance Project

Bion-11 (Experiment B11-16) Final Report

Behavior is an overt manifestation of underlying biology. As such, alterations in biological systems that result from spaceflight would be expected to evidence themselves in subtle or even pronounced changes in the behavior of that organism. These alterations in visible behavior may then indicate or even be diagnostic of alterations in the physical well-being of humans and other animals as they adapt to space environments or readapt to Earth--alterations that might not otherwise be detected without relatively invasive and frequently expensive procedures.

Moreover, behavior and performance constitute the central standard for evaluating the mission success of spaceflight ventures. The success or failure of any excursion into space is primarily indexed by the ability of astronauts and cosmonauts to perform the tasks and experiments of any particular mission, to land a re-entry vehicle after extended exposure to microgravity (as with the space shuttle), or to make time-critical and life-saving repairs or other decisions while in orbit (as with the recent Mir events). Thus, understanding the effects spaceflight on behavior and performance is inherently important, in addition to those insights that behavior can provide about the physiological consequences of space adaptation.

Thus, psychological adaptation to spaceflight encompasses the mental and emotional well-being of the crew and other animals as well as the behavior and performance of these individuals. Psychological aspects of space adaptation syndrome will continue to be important with the construction and occupation of the International Space Station. Extended exposure to a microgravity combined with heavy workload demands placed upon an international crew will exacerbate the challenges to psychomotor function, attention, motivation, learning, memory, communication, reasoning, judgment, and psychological well-being.

Since the earliest days of space travel, scientists have frequently employed nonhuman animal surrogates in studies of space adaptation syndrome. These animals afford the physiological similarity, controlled histories, size, weight, and time necessary to support meaningful experiments in precious few opportunities for spaceflight. With nonhuman primate species, these benefits are also complemented by substantial areas of psychological continuity with humans, so that topics of cognitive (e.g., perception, learning, memory) and psychosocial (e.g., stress, isolation) interest might also be investigated or controlled with defined opportunities for generalization to human behavior.

Scientific considerations, ethical concerns, and United States law dictates that studies of nonhuman primate species--whether on Earth or in space--must support and assess both the physical and the psychological well-being of the monkeys or apes maintained for research. Support for the psychological well-being of nonhuman primates involves addressing their needs

for comfort, companionship, challenge, and control. Although the comfort and companionship aspects of well-being can be addressed through the course of normal husbandry or care-taking procedures, primates' need for challenge or stimulation and control require special attention.

A computer-based environmental-enrichment system was developed with support from NASA specifically to provide challenge and control to macaques maintained for spaceflight research (Rumbaugh et al., 1989). This Psychomotor Test System (PTS) allows psychological experiments (e.g., studies of psychomotor control, attention, learning, memory, problem solving) to be translated into game-like tasks that provide a variety of challenges to the macaques. Additionally, the system yields control to the animals by permitting them to choose when to work (thus, when to receive nutritive treats) or when to rest, and frequently on which tasks to work. Data from ground-based investigations reveal that PTS activity is highly preferred and that the device does indeed support the psychological well-being of nonhuman primates (Washburn & Rumbaugh, 1992b; Washburn, Rumbaugh & Richardson, 1992). (Appendix A and Appendix B provide additional details on the uses of PTS that were supported by NASA grant NAG2-438.)

The present investigation was designed to identify the effects of spaceflight on behavior and performance as assessed with the PTS. Additionally, this project had two practical goals: (1) to train rhesus monkeys (*Macaca mulatta*) to walk in a controlled manner on a treadmill so that the effects of spaceflight could be studied on the behavior of locomotion, and (2) to provide an environmental enrichment device (PTS) that was known to support psychological well-being to flight-candidate monkeys both before and after the spaceflight.

Method

Subjects

The histories and selection criteria for the 25 male rhesus monkeys (*Macaca mulatta*) are documented in the Project Science Report. These animals ranged in age from 23 to 29 months at the outset of training (September, 1995), at which time they weighted about $2.4 \pm .3$ kg. During the course of training for this experiment, the monkeys also underwent surgeries and were trained or tested for other, complementary studies in this multi-disciplinary, international program of research.

From this pool of flight candidates, two monkeys (#357 and #484) were selected for spaceflight and two monkeys (#501, #534) were identified as control animals. The selection criteria have been described elsewhere (see Project Science Report), and included successful training for PTS and locomotion as well as other behavioral tasks, acceptable size, weight, and health, operational implant status, and good tolerance for acceleration effects or gravitational load. Prior to the flight (L-3), monkeys #357 and #484 weighted 4.9 kg. and 5.1 kg. respectively. Animals #501 and #534 were used in a "flight capsule / bios restraint" control test that began 17 days after recovery of the flight capsule, and weighed 5.3 kg. and 4.5 kg., respectively, at the

start of the R+17 test.

Apparatus

PTS hardware. A Project Hardware Report has been prepared to describe the array of hardware required to support the Bion-11 spaceflight. Special apparatus for the present experiment consisted of the Psychomotor Test System (PTS) and a motorized treadmill. As many as 8 PTS units were constructed at the Animal Care Facility, Institute for Biomedical Problems, Moscow, Russia. Each test system consisted of an IBM-compatible, 80386-based personal computer connected to a VGA color monitor. This equipment was positioned on a cart and surrounded on three sides by clear plastic panels. A standard analog joystick was mounted to the cart so that the handle extended horizontally through the protective plastic. The joystick was positioned so that it was centered below the monitor. A pellet dispenser was also mounted within the enclosure, with a tube that extended to a pellet cup mounted on the front surface of the cart. Thus, the PTS hardware was arranged such that the cart could be rolled and positioned in front of a monkeys' vivarium cage, permitting the animal to see stimuli on the screen, to manipulate the joystick, to hear sound feedback from the computer, and to retrieve pellets dispensed into the cup. At the same time, the computer itself and all wiring were protected from damage.

PTS software. The PTS also consists of a software package of computerized tasks designed to permit assessment of the effects of spaceflight on a variety of psychological systems. A battery of tasks was developed by Georgia State University scientists and was tested and proven in numerous studies using monkeys at the Sonny Carter Life Sciences Laboratory, Georgia State University. Three of these tasks were used in the present experiment (see Procedure, below). In each task, trials began with the presentation of computer-generated stimuli on the monitor. One stimulus, a 1.25 cm X 1.25 cm plus sign (+), was called the cursor and could be moved by manipulating the joystick. Moving the joystick handle caused the cursor to move on the screen at an angle isomorphic to the angle of joystick deflection and at a speed proportional to the degree of joystick deflection. Bringing the cursor into contact with any other computer-graphic stimulus was registered as a response. Correct responses were automatically reinforced with sound feedback (a rapidly rising sequence of tones) and a 190 mg fruit-flavored chow pellet. Trials were aborted if the monkey manipulated the joystick at least once and then ceased responding for 60 s. Following each trial, a variety of data were automatically recorded on the computer disk, including response latency (the time from presentation of the stimuli to the first movement of the joystick), response time (the time from first joystick movement until the end of a trial), and response accuracy. A new trial was initiated 5 s after each successful or aborted trial.

Treadmill. For the locomotion study, two treadmills were purchased and modified for use with the monkeys (see Experiment B11-04 Report, Edgerton et al., for additional details). A clear Lexan box was constructed atop the treadmill, permitting a monkey to be contained safely atop the treadmill belt. The 130 cm long X 80 cm high X 38 cm wide box had a door in the back

to allow a monkey to be transferred in or out, and a reward cup mounted outside the front to facilitate reinforcement. A hole (approximately 5 cm in diameter) was drilled directly above the pellet cup so that monkeys could reach out of the treadmill enclosure and retrieve rewards. Except for this hole, there was no surface within the treadmill enclosure that a monkey could hang onto or stand on other than the belt that covered the floor (and that moved when the treadmill motor was activated).

Training

Two significant objectives for the Behavior and Performance Project were:

- (1) to train rhesus monkeys on a subset of PTS tasks, so that
 - (a) the effects of spaceflight on performance could be assessed, and
 - (b) psychological well-being could be supported and assessed;
- (2) to train rhesus monkeys to walk bipedally and quadrupedally on a treadmill.

Significant hurdles challenged the success of both of these objectives. Prior to the present experiment, many rhesus monkeys had been trained to perform the battery of 18 PTS tasks at the Sonny Carter Life Sciences Laboratory in Atlanta, Georgia and at the NASA Ames Research Center in Moffett Field, California. However, the PTS training required for the present experiment depended heavily on the efforts of Russian co-investigators and technicians who had no prior experience with the PTS hardware and training protocol, required working with monkeys that were younger than any that had been trained on PTS prior to that date, and involved a tight training schedule in which the same 25 monkeys had to master PTS tasks and Russian behavioral tasks in just a few months. The locomotion training was similarly risky in that the training procedures had to be completely devised, tested, and implemented in a short period of time.

Procedure: PTS Training

All PTS tasks, programs, procedures, and criteria were selected after extensive testing and streamlining at the Sonny Carter Life Sciences Laboratory. The PTS tasks were arranged in a training curriculum to permit a naive monkey to learn to associate particular sound feedback with the delivery of food rewards (i.e., magazine training), to move the joystick in order to obtain reinforcement, and increasingly to control precisely the movements of a cursor through skillful manipulation of the joystick. The first task in this curriculum is called SIDE (see Rumbaugh et al., 1989). Each SIDE task session began with the cursor located in the middle of the screen, surrounded on all sides by blue walls that formed a rectangle around the border of the screen. Moving the cursor into contact with any target wall was registered as a correct response. In this way, the monkeys learned to move the joystick handle in order to obtain rewards.

The SIDE program automatically monitored performance over each block of 5 consecutive

trials. If mean response time (RT) across this block of trials was less than 3 seconds, the task was automatically made more difficult by removing one randomly selected target wall. Thus, the cursor might appear with three target walls instead of four. Responses to any target wall was registered as a correct response, as before; however, moving the cursor to the wall that had no blue border did not end the trial. Consequently, the monkeys had to learn to discriminate target from nontarget areas on the screen and to move the joystick in a direction corresponding to targets.

If mean RT over 5 consecutive trials exceeded 20 seconds, the task was automatically made easier by adding a target wall. Training continued in this way, with the number of target walls automatically titrated according to performance-based criteria. When only one target wall was on the screen (again, presented in random location each trial), the size of that wall was made to vary according to these same performance criteria. Thus, RTs below 3 seconds caused the single target wall to shrink or grow until the monkeys could move the cursor into contact with a small (2.5 cm X 2 cm) blue box on the screen.

When a monkey reached criterion on the SIDE task (200 trials of the smallest single target with a mean RT less than 3 seconds and fewer than 20% drop-outs, or trials aborted because the animal began but did not finish a trial), he was moved to the CHASE task. In the CHASE task, the monkey had to move the cursor into contact with the 2.5 cm X 2 cm blue box on the screen, as with SIDE. In CHASE however, the target stimulus began each trial in a randomly selected position and moved on the screen in a diagonal path, deflecting at 45 degree angles from any border of the viewing surface, at an approximate speed of 2.5 cm/s. The target stimulus moved whenever the cursor moved, but was stationary at any time that the joystick was not manipulated. Thus, the monkeys had to chase and catch the moving stimulus in order to obtain reinforcement.

For some animals, three additional tasks were introduced using a menu format called SELECT (Washburn, Hopkins & Rumbaugh, 1991). A PURSUIT tracking task was identical to CHASE, except that the monkeys were required to keep the cursor in contact with the moving target for 0 to 2.5 consecutive seconds before the trial ended. Errors (allowing the target to break contact with the cursor) resulted in resetting of the tracking timer. The matching-to-sample (MTS) task began with the cursor presented in the middle of the screen and a randomly generated stimulus presented in randomly selected position elsewhere on the screen (see also Washburn, Hopkins & Rumbaugh, 1989). This sample stimulus was generated using one of several algorithms for producing novel stimuli (e.g., checkerboard patterns with randomly chosen cells of the checkerboard filled with randomly selected colors, lexigrams formed by combining randomly selected geometric elements such as lines, triangles, and circles, etc.; see Washburn, 1990 for further details). When the cursor was brought into contact with the sample stimulus, two additional stimuli appeared in randomly selected, non-overlapping positions on the screen. One stimulus was identical to the sample, whereas the other was a second, non-matching form generated using the same stimulus algorithms described above. The monkeys' task was to move the cursor to the stimulus that matched the sample. Correct responses were reinforced, whereas errors resulted in a buzzing noise and no reward. The delayed matching-to-sample task (DMTS) was similar to MTS except that a 0 to 40 second delay intervened between the point at which the

cursor touched the sample and the presentation of the matching and non-matching stimulus. During this interval, the sample stimulus was removed from view and did not re-appear with the choice stimuli. Thus, the monkey had to recognize the sample from memory.

Each of these three tasks, plus SIDE and CHASE were represented on the computer screen by icons. Selection of an icon by bringing the cursor into contact resulted in the presentation of 5 trials of the corresponding task. Following the presentation of these 5 trials, the menu was again presented and the monkey was permitted to choose a new task. In addition to being the best way to promote psychological well-being, this SELECT menu format has been shown to result in reliably better performance on each available task. Finally, feasibility data collected at the Sonny Carter Life Sciences Laboratory in Atlanta suggested that young monkeys might learn the MTS, DMTS and PURSUIT tasks quite quickly, even while improving their performance on SIDE and CHASE, if trained in this fashion.

The monkeys were assigned to one of four groups. Each week, one group of six monkeys was given access to PTS tasks while the animals occupied their vivarium cages. During daylight hours, these monkeys could work whenever they wanted by reaching through the bars of their home cages to manipulate the joystick or to retrieve pellets. During this period, the other three groups of monkeys were trained on the Russian behavioral tasks. Thus, each monkey worked on PTS for one week per four-week cycle. As monkeys were dropped from the flight pool for various reasons (see Project Report - Science), access to PTS was made more frequent.

Procedure: Locomotion Training

Training the monkeys to walk on the treadmill essentially involved three stages. For the first session or two, monkeys were transferred one at a time to the treadmill and allowed to explore the new surroundings. It was important to habituate the monkeys to the treadmill chamber because the enclosure was constructed of transparent Lexan, outside of which a variety of people and equipment could be seen. When the monkey had calmed within the treadmill enclosure and was safely away from the back wall, the treadmill motor was started briefly. The movement of the belt and the noise that accompanied it startled the monkeys, but they quickly habituated to these events as well.

When the monkeys had acclimated to the treadmill enclosure and to brief operation of the belt and motor, the second phase of training was initiated. The monkeys were shaped to make first one, then two, then increasingly long series of steps forward as the treadmill belt moved at 1 to 2 miles per hour. Appropriate steps were reinforced by turning off the treadmill motor (which stopped the belt) and presenting a pellet or small piece of food (fruit or nut) in the reward cup. Belt speed was manipulated within the specified range in order to find the pace of comfortable gait for each monkey. Trainers attempted to extinguish behaviors such as hopping, walking backward, and stopping. Attempts by the monkey to lift itself off of the moving belt were generally unsuccessful, although in some cases the walls of the enclosure had to be coated with a thin film of lubricant to prevent monkeys from suspending themselves between the Lexan panels.

The final phase of training involved teaching the monkeys either to walk in a bipedal or quadrupedal fashion. It was originally hoped that monkeys could be trained to walk bipedally or quadrupedally on demand, given some visible stimulus. However, pilot work discouraged this possibility but suggested instead that the monkeys could rather easily be shaped to execute bipedal or quadrupedal steps. In Moscow, this final phase of training took the form of getting all monkeys to walk in a quadrupedal fashion. Given that only a few steps could be made and recorded after the flight, it was determined that eliminating individual differences and requiring quadrupedal walking by all monkeys was most efficient.

Results: PTS Training

All 25 flight-pool monkeys achieved the performance criterion on the SIDE task. Thus, each acquired the basic psychomotor skills required to control a cursor by manipulating a joystick. By the sixth week of training, the 22 monkeys that remained in the flight pool had satisfied the training criteria for the CHASE task. On average, these monkeys produced over 7,000 CHASE trials each.

Although 16 monkeys received some training on the PURSUIT, MTS and DMTS tasks, progress toward criterion on these three tasks--introduced simultaneously and in a novel, menu format--was slower than with CHASE training. This fact, combined with the tight training schedule, the demands of training for locomotion and the Russian behavioral tasks, and the importance of maximizing the data acquired for each task, resulted in the decision by the team of investigators to discontinue training on PURSUIT, MTS and DMTS. Subsequent sessions with flight pool animals focused on CHASE performance.

Because monkeys were tested in squads, with variable periods of times between PTS administrations, we analyzed CHASE response time to determine whether it varied reliably as a function of the time between training bouts. Performance in the first 100 trials of CHASE was uncorrelated with the number of days since last exposure to CHASE ($r = -.01$).

The four monkeys that served in the present experiment followed this general pattern as well:

	<u>SIDE Criterion Met</u>	<u>CHASE Criterion Met</u>
Monkey #357	Week 2	Week 4
Monkey #484	Week 4	Week 6
Monkey #501	Week 2	Week 4
Monkey #534	Week 2	Week 4

Thus, a large and rich corpus of training data were obtained for this colony of monkeys, and particularly for flight-candidate animals. Although some problems were encountered, it is clear that PTS exported quite successfully to the laboratory in Moscow and the novel aspects of

the training environment there. It is anticipated that future analyses of the training data will yield additional, publishable information about learning and performance by young rhesus monkeys.

Results: Locomotion Training.

Each monkey rapidly habituated to the treadmill chamber, and was easily trained to execute a series of steps as the treadmill belt moved at 1 to 2 miles per hour. Consistent with the training protocol, the monkeys were re-trained each session as each involved the gradual increase of the number of steps produced by the monkeys, beginning with one. Given the ease with which this was accomplished, no data were recorded for each session other than housekeeping variables (date, time, duration) and general comments.

Each monkey's style of walking on the treadmill (bipedal versus quadrupedal) tended to be stable across sessions.

Monkey #357 received his first treadmill session on 26-Mar-96, and reliably produced satisfactory quadrupedal walking by his seventh training session (9-Apr-96, representing about 61 minutes in training). Monkeys #484 received his first treadmill session on 25-Mar-96, and produced reliable bipedal steps in his fifth session (29-Mar-96, after about 32 cumulative minutes of training). Monkey #501 was trained first on 21-Mar-96, and repeatedly tried in his first few sessions to suspend himself between the walls of the treadmill chamber above the treadmill belt. Notwithstanding, he was reliably producing quadrupedal steps after 75 minutes (11-Apr-96). Monkey #534 walked bipedally after a total of about 63 minutes on the treadmill (11-April-96), with sessions beginning on 25-Mar-96.

Flight Experiment

Two additional objectives of the Behavior and Performance Project were:

- (1) to assay psychological processes and behavior pre- and post-flight; and
- (2) to support, monitor and study the psychological well-being of the rhesus monkeys (as revealed by overt behavior and, indirectly, by task performance) before, during and after the flight.

Unfortunately, PTS could not be made available to the monkeys during the spaceflight. Thus, an experiment was designed in which performance after the flight could be compared to baseline measures taken prior to spaceflight. Any differences in performance could then be compared to changes in performance observed after control sessions in which all conditions except actual spaceflight were duplicated both on a between-groups and a within-subjects basis.

Procedure: PTS

CHASE task training continued with each of the flight pool monkeys, even as monkeys were eliminated from the flight pool due to failure to satisfy one or more of the criteria for flight eligibility (e.g., health concerns, poor g-tolerance, failure to learn the Russian behavioral tasks). About a year after training was initiated, each monkey was tested in a three-day metabolic test to provide baseline measures of PTS performance. During this test, the monkeys were housed in cages that permitted collection of metabolic data (i.e., urine) while affording access to PTS for 16 hours/day. Monkey #357 and #534 completed this test at L-108 (7-Sept-96), whereas #501 and #484 finished on L-95 (20-Sept-96) and L-88 (27-Sept-96) respectively.

These monkeys were moved to the launch site on L-29. We were fortunate to obtain about 2 hours/day of pre-flight PTS data at the launch site on L-26 to L-13. Although the animals were in a novel environment and were not in metabolism cages during this period, these data do provide additional baseline measures to reveal whether performance had changed in the 2 to 3 months since the metabolic test.

On 24-Dec-96, two monkeys (#357 and #484) were launched on a 14-day mission. The control monkeys were returned to Moscow at this time. Details of the launch, flight and recovery are discussed in the Project Report - Science. Details of activities by other investigators on R+0 and R+1 (as well as surgeries or tests conducted before the flight) can be found in the science reports for other discipline teams.

Post-flight PTS tests were assigned for monkeys #357 and #484 on R+2 to R+4. These tests, like the pre-flight measures, were scheduled for the metabolic cages with no other science activities.

A between-group control test was conducted, beginning on R+17. This test was designed to simulate all of the conditions experienced by the flight monkeys except for those directly related to spaceflight (i.e., launch, microgravity, re-entry). The restraint system, the schedule of feedings and administration of the Russian behavioral tasks, the ambient light and temperature conditions, and other variables were controlled in this ground-based study to duplicate those of Bion-11. Thus, two monkeys (#501 and #534) were placed in Bios restraint chairs for 14 days under conditions that simulated those experienced by monkeys #357 and #484. Following these 14 days, the monkeys were given access to PTS in the metabolic cages. These post-test sessions were scheduled for R+37 to R+39, corresponding (as for the flight monkeys) with the three days following the suite of tests and surgeries scheduled on the day after restraint.

A within-subject control test was scheduled to begin on R+45. This test was designed to replicate the R+17 control test, but using the two flight monkeys (#357 and #484). Consistent with the flight and between-group control test, post-test PTS access was scheduled for R+64 to R+66 in metabolism tests.

Procedure: Well-being Assessment

This experiment was not designed to assess the effectiveness of PTS as a device for supporting the psychological well-being of rhesus monkeys. Indeed, this fact has already been established through prior investigations. Rather, PTS was made available to monkeys as frequently as possible, and monkeys worked on an *ad libitum* basis to provide challenges and rewards for themselves.

At the same time, we did attempt to collect objective assessments of each monkey's behavior and well-being on an opportunistic basis. A well-being checklist (below) was constructed and provided to the American and Russian trainers and caretakers at the Institute for Biomedical Problems in Moscow. (A Russian translation was used by IMPB staff.) Given the frequent changeover of American personnel in Moscow and given the arduous work schedule of all persons involved, it was impossible to require daily assessments by multiple observers under controlled conditions. Rather, we attempted to obtain as many observations as possible, recording during each the incidence of behaviors that indicate psychological distress (e.g., over-grooming, stereotypy, aggression, inactivity) or physical illness.

DATE: TIME: MONKEY:

1. Sleep status	Normal	Normal
2. PTS available?	Yes	No
3. Singly housed?	No	No
4. See other monkeys?	No	No
5. Hear other monkeys?	No	No
6. Non-compatible monkeys nearby?	No	No
7. Enrichment devices other than PTS?	No	No
8. Restraint status	Restrainted	Restrainted
9. Choices/control available?	No	No
10. Intellectual challenges?	No	No

1. Overall Appearance of health	Excellent	Good	Fair	Poor	Very Poor
2. Hair coat	Excellent	Good	Fair	Poor	Very Poor
3. Self-inflicted wounds	None		Minor	Frequent	Severe
4. Eyes	Excellent	Good	Fair	Poor	Very Poor
5. Discharge from eyes or nose	None		Minor	Moderate	Severe
6. Appetite	Excellent	Good	Fair	Poor	Very Poor
7. Weight change	Normal			Abnormal	
8. Feces volume	Normal			Abnormal	
9. Feces condition	Normal		Loose	Hardened	
10. Body posture	Normal			Abnormal	
11. Bleeding or vomiting	No			Yes	
12. Signs of pain or discomfort	None		Little	Moderate	Severe

1. Alertness	Very Alert	Good	Fair	Poor	Very Poor
2. Unprovoked aggression	None	Little	Moderate	Constant	Severe
3. Activity	Normal			Littlest, Payer	Excessive
4. Response to stimuli	Normal			Agitated	Very Poor
5. Distress vocalizations	None		Few	Frequent	Very Frequent
6. Stereotypy	None	Infrequent	Moderate	Frequent	Constant
7. Grimacing	None		Occasional	Frequent	Constant
8. Curiosity/interest in environment	Normal			Abnormal	Unresponsive
9. Rest/sleep patterns	Normal			Abnormal	

Comment:

Activity Budget		
Activity	%	Work Area (for notes, times, etc.)
REST / SLEEP		
PTS DIRECTED		
SELF-AGGRESSIVE		
OTHER-AGGRESSIVE		
EATING / DRINKING		
NORMAL GROOMING		
CAGE- or CHAIR-DIRECTED		
STEREOTYPY		
OTHER (SPECIFY)		

In addition to these overt behaviors coded before or after flight (or control tests), we proposed to examine the videotapes from the in-flight or control tests for indices of well-being.

Procedure: Locomotion

The method and results of the locomotion study are reviewed in the report for Experiment B11-04 (Edgerton et al.).

Results: PTS

Within-subject comparisons. As is detailed in the Project Science Report, monkey #357 died from aspiration asphyxia following the procedures on R+1 and prior to the collection of any post-flight PTS data. Additionally, monkey #484 experienced substantial illness in the days following the flight and R+1 tests. As a consequence, access to PTS was extremely limited for

this monkey, who was maintained under conditions of rest and near-continuous veterinary monitoring. Only one CHASE trial was recorded in the few minutes PTS was available on R+3, with but four trials obtained on R+4. The 57 CHASE trials obtained on R+5 were augmented with data from the monkey in its vivarium cage over the subsequent two days.

These limits in the number of trials obtained following flight and R+45 conditions reflect reliable differences in monkey #484's productivity across conditions (pre-flight, post-flight, pre-R+45, post-R+45). Because of variations in the amount of time that PTS was available to the monkey each day, a simple analysis of "number of trials per day" was inappropriate. Rather, response latency (the time from the onset of a trial to the first movement of the cursor) was used as one estimate of the monkey's motivation to work. Significantly more time elapsed before monkey #484 responded to trials after the flight and the R+45 test than in baseline (pre-flight or pre-R+45) conditions, $E(1, 122) = 17.46$, $p < .01$ (pretest mean latency = 59 s, post-test mean response latency = 401 s). Thus, CHASE trials were available but idle following the restraint period and post-test surgical activities.

Those post-flight data that were collected were compared with pre-flight data (from the metabolic test and the launch site) and with data collected before and after the R+45 control test with monkey #484. After discarding trials that were more than three standard deviations beyond the mean, descriptive statistics and confidence intervals were computed for each condition. In the sessions following spaceflight and R+1 procedures, mean response times on the CHASE task were reliably longer than baseline measures obtained prior to the flight ($p < .05$). Performance before and after the R+45 control test did not differ from the baseline data.

	Mean <u>RT</u>	Standard <u>Error</u>	<u>Median</u>	<u>N trials</u>
Monkey #484 pre-flight metabolic test	3.36 s	0.08 s	2.60 s	1,084
Monkey #484 launch site	3.28 s	0.15 s	2.50 s	320
Monkey #484 post-flight	4.32 s	0.27 s	3.20 s	173
Monkey #484 before R+45 control test	3.13 s	0.09 s	2.20 s	1,072
Monkey #484 after R+45 control test	3.79 s	0.30 s	2.40 s	115

Note that response times were relatively elevated after the R+45 control test as well as following flight, and statistical analyses are inconsistent regarding inferences on this point. The 95% confidence interval for the R+45 tests included the pre-flight means, suggesting that 3.79 s was not reliably different from the 3.36 s baseline. Conversely, repeated-measures analysis of variance (which utilizes only the first 115 trials of each condition) did reveal reliable test effects (longer response times in the post-tests than the pre-tests, $p < .01$) and flight-condition effects (longer response times around the flight than around the R+45 control test, $p < .01$) but no Test by Flight-condition interaction ($E(1, 106) = 13.22, 7.75$, and 1.51 respectively). This would suggest that performance after restraint post-restraint surgeries is compromised whether or not the restraint period includes spaceflight variables.

In addition to omitting much of the data, the repeated-measures analysis requires several shaky assumptions, including the implication of a correlation between or matching of test conditions. Trial response times were in fact uncorrelated across and within conditions ($p > .10$). A between-conditions analysis of variance would appear to be more appropriate than repeated-measures statistics for these data. Such a test revealed a reliable effect of condition, $F(4, 2756) = 7.71$, $p < .01$; post hoc comparisons revealed response times in the post-flight condition to be significantly longer than all baseline measures, but no other differences were statistically reliable ($HSD = 0.78$ s). That is, monkey #484 performed comparably in all tests except for the days immediately following spaceflight, at which time performance was reliably slower.

This conclusion was also supported by analysis of the median data, which are important given that the distribution of response times was skewed and subject to extreme values. A nonparametric median test for order revealed that only the response times in the post-flight test differed reliably from the grand median estimate of monkey #484's performance on CHASE ($Z = 3.67$, $p < .01$).

Between-groups comparisons: The death of monkey #357 was costly in terms of within-subject comparisons as it eliminated the possibility of inter-subject replication of the analyses above. The absence of data from that monkey is even more deleterious to the between-groups comparisons as it results in a flight group with an N of 1. Notwithstanding, comparison of performance by monkeys #501 and #534 with the data from #484 discussed above yields several interesting effects.

Significantly fewer trials were obtained in the three days following flight or the R+45 test than in the three days of the metabolic test. Confidence intervals for these means suggest that they represent different populations ($p < .01$). However, this effect did not interact reliably with flight condition. Thus, all three monkeys worked less after the restraint+anesthesia+surgery, irrespective of whether the 14 days of restraint were on Earth or in space.

	<u>Mean Number of Trials</u>	<u>Standard Error</u>
Pretest	1,206.8	92.2
Post-test	294.5	0.9

These differences are also reflected in different response rates (responses per minute in which PTS was available) before and after the flight or R+17 tests (mean = 0.87 trials/minute before and 0.28 trials/minute after the restraint+anesthesia+surgery treatment). These significant differences are insensitive to differences in the amount of time PTS was available across days, and show the same pattern of results: less productivity in post-tests irrespective of flight condition.

Despite restrictions in sample size, reliable differences can also be observed in the comparison of flight- versus control-monkey response times. As was reported for within-subject analyses above, response times on the CHASE task after the R+17 test were comparable to

baseline measures for monkeys #501 and #534 ($p > .10$); however, 484's performance following the flight was reliably different than pre-flight performance ($p < .05$). This between-groups analysis underscores our interpretation of the conflicting within-subject analyses: Response times on this psychomotor task were slowed by variables unique to #484's spaceflight and recovery.

	<u>Mean RT</u>	<u>Standard Error</u>	<u>Median</u>	<u>N trials</u>
Monkey #501 pre-flight metabolic test	3.31 s	0.11 s	2.60 s	1231
Monkey #501 launch site	2.69 s	0.10 s	2.00 s	605
Monkey #501 after the R+17 control test	2.93 s	0.11 s	2.25 s	801
Monkey #534 pre-flight metabolic test	2.85 s	0.12 s	2.20 s	1444
Monkey #534 launch site	2.87 s	0.12 s	2.30 s	375
Monkey #534 after the R+17 control test	3.00 s	0.12 s	2.40 s	414

Response topography was also recorded in the PTS CHASE task. This record of every target and cursor movement during a trial was analyzed to determine the degree to which the path of responding manifest by each monkey on each trial approximated the optimal path for that trial. The index of optimality is the semipartial correlation coefficient between observed path and optimal path, after eliminating any covariance from the target's actual position (see Washburn & Rumbaugh, 1992a). Higher values reflect better target prediction or more optimal responding.

The observed path of responding was significantly correlated with the optimal path for all three monkeys, although less than 10% of the variance in path data is accounted for by the hypothetical optimal path. The path of responding was significantly less optimal (i.e., correlations were reduced) following the flight or R+17 conditions and in the pre-test samples, $F(1, 1) = 243.00$, $p < .05$. However, this difference did not interact with flight condition.

	<u>Pre-flight or Pre-R+17</u>	<u>Post-flight or Post-R+17</u>
Monkey #484	$r = .17$	$r = .10$
Monkey #501	$r = .21$	$r = .15$
Monkey #534	$r = .33$	$r = .28$

Results: Well-being

First, it should be noted that each of the effects discussed above may reflect variations in psychological well-being or readiness to adapt. Abnormal patterns of trial productivity or performance are likely to be indirect measures of psychological fitness. This suggests the conclusion that the monkeys were less psychologically well following restraint and surgery, and that the effect was particularly pronounced for monkey #484 following spaceflight.

To investigate this claim further, performance on the CHASE task was analyzed against a composite score computed for the well-being checklist (above). The formula for producing this score was straightforward: A score (from 1 to 5) was assigned to each of the categories on the checklist, with a higher score reflecting greater well-being. For example, no observed stereotypy would add 5 points to a monkey's score, occasional (infrequent) stereotypy resulted in 4 points, and so forth. This score did not reflect any of the first 10 items or the activity budget on page 2 of the checklist.

It is noteworthy that no category obviously reflects how a monkey was performing on PTS, although there are certainly areas in which PTS activity might indirectly influence the scores. For example, animals who perform many trials (and thus receive many pellets) might be evaluated having good appetite--if the rater monitored the contents of the pellet dispenser. Additionally, we have already reported (Washburn & Rumbaugh, 1992b) that PTS activity replaces relatively undesirable behavior like stereotypy and distress vocalizations. Thus, animals that are working on PTS tasks cannot concurrently be engaged in maladaptive behaviors. Notwithstanding, it is noteworthy that CHASE response time correlated reliably with well-being score ($r = .77$, $p < .05$). In particular, it is clear that both the well-being scores and the PTS measures reflect the malaise experienced by monkey #484 in the days following the spaceflight.

Analysis of the videotapes from flight and control tests could not proceed as intended because the tapes from the R+17 and R+45 control tests were never delivered to Behavior and Performance Project scientists. Without these control data, the best that can be provided is a general description of each monkey's behavior during spaceflight. In general, the flight videotapes showed the animals to rest or sleep most of the time. The animals appeared to be comfortable, and no distress behaviors were observed (see Project Science Report and the discussion below for further consideration of these videotapes).

Conclusions

1. PTS performance was adversely affected by the suite of surgeries, anesthesia and other procedures scheduled for the first day after flight or control tests. This result is consistent with the Behavior and Performance Project findings in the Adult Rhesus Restraint Test (Washburn and Rumbaugh, 1995). In that study, PTS performance on a variety of tasks was unaffected by 20 days of restraint, but was disrupted by the biopsies and other tests that intervened between restraint and post-test conditions. In the present data, all three monkeys showed some disruption in post-flight performance. There were disruptions in trial productivity and response optimality following 14 days of restraint plus one day of physiological measurements, irrespective of flight condition (spaceflight versus ground-based control).

- a. It appears that trial productivity, or motivation to work, is the primary behavioral measure affected by the post-test combination of anesthesia and surgeries. All three monkeys exhibited reductions in the number of trials produced or increases in the latency to initiate a trial in post-flight, post-R+17, or post-R+45 sessions.

b. In prior research (Washburn & Rumbaugh, 1992b), we have demonstrated that monkeys will continue to perform PTS tasks--albeit at reduced levels of productivity--even when the animals are not motivated to eat. It is possible that reductions in trial production reflected the physical health of the monkeys and a transient avoidance of food.

c. It is also clear that competence and productivity are related, such that fewer trials are produced under conditions in which monkeys have difficulty capturing the target stimulus. This possibility is borne out in the analysis of path data and in chronometric data from monkey #484, but not in the response-time analyses for the control monkeys.

d. "Monkeys' eagerness to work on PTS tasks" has frequently been cited among the evidence that PTS is enriching for rhesus monkeys. One might then conclude that reductions in trial productivity reflect reductions in the enrichment value of PTS rather than changes in the well-being of the monkeys. Regardless of whether the monkeys were physically incapable of producing many tasks or were psychologically unmotivated to engage in task activities at characteristically high levels, it is significant that the monkeys had the option of choosing for themselves when and whether to work--even in the days following recovery from spaceflight.

2. Moreover, there appears to be a reliable effect of spaceflight on PTS performance in addition to any effects of post-flight surgery or anesthesia. All of the effects reported here were relatively greater for the flight monkey than for the control monkeys. Moreover, CHASE response times were disrupted only following the spaceflight for monkey #484. Unfortunately, this effect could not be replicated (either within-subjects or between-groups) because no post-flight data were obtained from #357. This is particularly problematic because monkey #484 became ill after the procedures on R+1, but not following the R+45 test. Well-being checklists reflect the fact that this monkey was visibly ill. Thus, it is unclear whether the disruption in CHASE response time is the result of spaceflight per se or of malaise and the procedures introduced to treat it.

a. However, it seems that one clear conclusion from the interdisciplinary research on Bion-11 is that the post-flight malaise and even the death of monkey #357 were not events independent of spaceflight. Rather, it is the interaction of "recovery from spaceflight" and "R+1 anesthesia and surgery" variables that appears to have resulted in both the aspiration of monkey #357 and the illness of monkey #484 (see Project Report - Science). Such illness did not follow the suite of anesthesia, biopsies, and procedures that followed the R+17 and R+45 tests. Thus, although we cannot disambiguate whether alterations in #484's performance reflect spaceflight or illness, the distinction is made inconsequential by the causal relation between spaceflight and illness. In other words, disruption of CHASE performance may have reflected the direct effects of spaceflight (e.g., poor motor coordination resulting from physical alterations in muscle), or indirect effects of spaceflight (e.g., illness induced by the interaction of space adaptation and post-flight biomedical procedures).

b. That said, it should be acknowledged that the procedures and precautions that were undertaken because monkey #484 was ill are unique to the post-flight period (see report of Veterinary Team). For example, monkey #484 spent the night and day of R+2 in a restraint chair rather than a metabolic cage. This procedure and the continuous vigil maintained by veterinarians and caretakers were implemented to ensure that monkey #484 would not aspirate fluids or experience other unforeseen complications. The medicines and veterinary attention that were given to #484 in the R+1 to R+4 period were not duplicated in the R+45 study. Thus, it is impossible to determine whether the present disruptions in performance reflect spaceflight+malaise effects or the effects of actions taken to remedy discomfort and malaise.

c. Determination of whether the effect of spaceflight on psychomotor performance is direct or indirect may be illuminated by the results of other Bion-11 experiments, particularly those involving in-flight and post-flight behavioral testing (Experiment B11-24). It seems most likely, however, that we will need to replicate the disruption of performance with one or more additional animals tested in or after extended exposure to conditions of altered gravitation.

3. Objective assessments of psychological well-being based on overt behaviors were reliably correlated with variations in CHASE task performance. Despite the fact that the individuals making the ratings had no way of knowing how quickly each monkey was capturing the target, these response times were related to ratings of physical appearance (e.g., hair, feces, discharge) and behavior (e.g., alertness, aggression, stereotypy).

a. There is no uniformly accepted method for assessing psychological well-being. The checklist approach used here is frequently employed, and has been used successfully in our prior investigations. However, we have also hypothesized that performance measures can be sensitive indices of psychological well-being. The present findings are the first data actually to support this relation. Because logistical difficulties prevented multiple observations of each monkey on each day, these data must be seen as exploratory and descriptive in nature. Notwithstanding, the prospects are very encouraging for further studies of performance indices of psychological well-being.

b. Analysis of the flight videotape should similarly be seen as descriptive rather than inferential in nature. In part, this reflects the absence of control data (from the R+17 and R+45 tests) against which to compare flight behaviors. Additionally, however, it is the case that little behavior other than "sleep or rest" is apparent on the flight videotape (see Project Report - Science for more details on the range of behaviors revealed in downlinked video). Indeed, the monkeys appeared clearly to be comfortable and to be free of distress, but appeared generally to lack stimulation and challenge except for those times when the Russian behavioral tests were available. In this sense, the videotape provides compelling evidence that, during spaceflight and control tests, nonhuman primates require continuous ad lib access to engaging behavioral tasks like the eye-head-

hand program and those provided by PTS. They are curious and active animals that seek stimulation and challenge, and for whom such tasks should both greatly aid adaptation and also be diagnostic of it.

Acknowledgments

This experiment was supported by grant NAG2-438 from the National Aeronautics and Space Administration to Georgia State University. The successful completion of this study reflects the expertise and efforts of many individuals, including our fellow scientists, the engineers, and the management and support team that comprised the Bion-11 project. In particular, the efforts of Jonathan Gullledge, Jane Patton, Leslie Berke and Mary Williams were essential to the success of this project.

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Appendix A:
Bibliography of Publications and Presentations supported by NASA Grant NAG2-438
1987 - 1999

The Psychomotor Test System (PTS; also known by the name of its prototype, the Language Research Center's Computerized Test System) was developed with support from NASA for ground- and flight-based research and enrichment of nonhuman primates. In the years since its 1987 development, the PTS has proven to be revolutionary as an apparatus for comparative studies of behavior and performance, and has been shown to be unsurpassed as a tool for supporting the psychological well-being of rhesus monkeys maintained for research purposes. To date, support from NASA grant NAG2-438 has directly led to more than 150 publications and professional presentations.

Versions of the PTS are now in use at more than three dozen laboratories across the United States and around the world. Clearly, the comparative literature on the biobehavioral bases of learning and performance, and how these processes are influenced by a variety of environmental and subject variables (including those related to spaceflight) will continue to benefit for years to come from the funds NASA provided through NAG2-438.

Refereed-Journal Publications (reverse chronological order)

Washburn, D. A., Rumbaugh, D. M., Richardson, W. K., Shlyk, G. G., & Vassilieva, O. N. (In press). PTS performance by flight- and control-group macaques. Journal of Gravitational Physiology.

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Gullledge, J. P., Washburn, D. A., & Rumbaugh, D. M. (1999, November). Judgments of Numeric Symbols and Quantities by Macaques. Paper presented at the meeting of the Psychonomic Society, Los Angeles, CA.

Washburn, D. A., & Gullledge, J. P. (1999, November). The "Monkey Business" of Computer Games. Paper presented at the meeting of the Society for Computers in Psychology, Los Angeles, CA.

Washburn, D. A. (1999, April). Time Estimation and Concentration. Paper presented at the meeting of the Southern Society for Philosophy and Psychology, Louisville, KY.

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Washburn, D. A., Rulon, M. J., & Gullledge, J. P. (1999, March). Who Needs a Mouse? Joystick Manipulation by a Rat!. Poster presented at the meeting of the Southeastern Psychological Association, Savannah, GA.

Washburn, D. A. (1998, November). Chronometric and Pupillometric Indices of Planning. Paper at the meeting of the Psychonomic Society, Dallas, TX.

Washburn, D. A., Raby, P. R., & Greenidge, J. (1998, November). Using Web-Based Games to Improve Training. Paper at the meeting of the Society for Computers in Psychology, Dallas, TX.

Washburn, D. A., & Putney, R. T. (1998, August). Attention Profiles of Boredom Proneness and Cognitive Failure. Poster at the meeting of the American Psychological Association, San Francisco, CA.

Washburn, D. A., Smith, J. D., & Filion, C. M. (1998, August). "Meaningful Failures" in Learning. Poster at the meeting of the American Psychological Association, San Francisco, CA.

Washburn, D. A., Rumbaugh, D. M., Richardson, W. K., Gullledge, J. P., Shlyk, G. G., Vasilieva, O. N.

- (1998, June). PTS Performance by Flight- and Control-Group Macaques. Paper at the XI Conference on Space Biology and Aerospace Medicine, Moscow Russia.
- Hodgson, J. A., Wichayanuparp, S., Recktenwald, M. R., Roy, R. R., McCall, G., Washburn, D. A., Fanton, J. W., Riazanski, S., Kozlovskaya, I. & Edgerton, V. R. (1988, June). Daily Activity Levels in Rhesus Hindlimb Muscles. Paper at the XI Conference on Space Biology and Aerospace Medicine, Moscow Russia.
- Recktenwald, M. R., Hodgson, J. A., Roy, R. R., Riazanski, S., McCall, G., Kozlovskaya, I., Washburn, D. A., Fanton, J., & Edgerton, V. R. (1998, June). Quadrupedal Locomotion in Rhesus after 14 Days of Spaceflight. Paper at the XI Conference on Space Biology and Aerospace Medicine, Moscow Russia.
- Washburn, D. A., Smith, J. D., & Fillion, C. M. (1998, April). What Can We Learn from "Failures to Learn"? Paper at the meeting of the Southern Society for Philosophy and Psychology, New Orleans, LA.
- Shields, W. E., Smith, J. D., & Washburn, D. A. (1998, April). Nonverbal Judgments of Knowing by Humans and Rhesus Monkeys. Paper at the meeting of the Southern Society for Philosophy and Psychology, New Orleans, LA.
- Washburn, D. A., & Putney, R. T. (1997, November). Pop-out Distractors in Visual Search. Paper at the meeting of the Psychonomics Society, Philadelphia, PA.
- Washburn, D. A., Thompson, R. K. R., & Oden, D. L. (1997, November). Monkeys Trained with Same/Different Symbols Do Not Match Relations. Paper at the meeting of the Psychonomics Society, Philadelphia, PA.
- Washburn, D. A. (1997, May). Recognition and Recall Components of Monkey Memory. Poster presented at the meeting of the American Psychological Society, Washington, DC.
- Gulledge, J. P., & Washburn, D. A. (1997, April). Visual and Spatial Memory Performance by Humans, Apes, and Monkeys. Poster at the meeting of the Southeastern Psychological Association, Atlanta, GA.
- Gulledge, J. P., & Washburn, D. A. (1997, March). Why Monkeys Can't Concentrate: an Investigation of Visual-spatial Memory. Paper presented at the meeting of the Southern Society for Philosophy and Psychology, Atlanta, GA.
- Washburn, D. A., & Rumbaugh, D. M. (1996, November). Processing Speed and Intelligence: Is Faster Better? Paper presented at the meeting of the Psychonomic Society, Chicago, IL.
- Shields, W. E., Smith, J. D., & Washburn, D. A. (1996, November). Memory Monitoring by Rhesus Monkeys. Poster presented at the annual meeting of the Psychonomic Society, Chicago, IL.
- Washburn, D. A., Putney, R. T., & Henderson, B. (1996, October). Getting training moving: Manipulations of procedural difficulty in computerized instruction. Paper presented to the meeting of Human Factors Atlanta, Atlanta, GA.
- Washburn, D. A., Rogers, W. A., & Fisk, A. D. (1996, April). Attention: Principles and phenomena. Paper presented at the meeting of the Southern Society for Philosophy and Psychology, Nashville, TN.
- Gulledge, J. P., & Washburn, D. A. (1996, April). Rhesus monkeys' reviews of video reinforcement: Two thumbs down. Paper presented at the meeting of the Southern Society for Philosophy and Psychology,

Nashville, TN.

Washburn, D. A., & Gullledge, J. P. (1995, November). The capacity of visuospatial memory for humans, apes, and monkeys. Paper presented to the meeting of the Psychonomic Society, Los Angeles, CA.

Filion, C., Washburn, D. A., & Frigaszy, D. M. (1995, June). Trajectory estimation by rhesus macaques. Poster presented at the annual meeting of the American Psychological Society, New York, NY.

Shields, W., Washburn, D. A., & Smith, D. A. (1995, June). Uncertainty in same-different judgments. Poster presented at the annual meeting of the American Psychological Society, New York, NY.

Washburn, D. A. (1995, April). A Comparative Investigation of Working Memory: Rehearsal in the Sketchpad? Paper presented at the meeting of the Southern Society for Philosophy and Psychology, Virginia Beach, VA.

Washburn, D. A., Sevcik, R. A., Rumbaugh, D. M., & Ronski, M. A. (1995, April). The Psychomotor Test System for Research and Education. Paper presented at the Life Sciences and Space Medicine Conference and Exhibition '95, Houston, TX.

Washburn, D. A., Putney, R. T., & Ukuku, E. E. (1995, March). Using Stimulus Movement to Enhance Training of Symbol Meanings. Paper presented at the meeting of the Southeastern Psychological Association, Savannah, GA.

Washburn, D. A., & Gullledge, J. P. (1994, November). Game-like Tasks: Leveling the Playing Field. Paper presented to the Society for Computers in Psychology, St. Louis, MO.

Washburn, D. A. (1994, August). What Animal Cognition Tells Us about Human Cognition. Paper presented at the conference of the Cognitive Science Society, Atlanta, GA.

Smith, J. D., Shields, W. E., Washburn, D. A., & Allendoerfer, K. R. (1994, August). Indifferent differences: The "Uncertain" Response in a Relational-Judgment Task. Paper presented at the 7th International Conference on Systems Research, Information, and Cybernetics, Baden-Baden, Germany.

Washburn, D. A. (1994, August). Monkeys in Outer Space. Paper presented in the Fernbank Museum of Natural History Summer lecture Series, Atlanta, GA.

Washburn, D. A. (1994, July). Physical and Semantic Features in Visual Search Performance by Humans and Monkeys. Poster presented at the meeting of the American Psychological Society, Washington, DC.

Washburn, D. A. (1993, November). Numerousness judgments by monkeys and computers. Paper presented at the meeting of the Society for Computers in Psychology, Washington, DC.

Washburn, D. A. (1993, August). Lateralization of perceptual inspection in joystick-using macaques. Paper presented at the meeting of the American Society of Primatologists, Sturbridge, MA.

Washburn, D. A., Harper, S., & Rumbaugh, D. M. (1993, August). Computer-task testing in the social milieu. Paper presented at the meeting of the American Society of Primatologists, Sturbridge, MA.

Washburn, D. A., Astur, R. S., & Raby, P. R. (1993, June). Sources of forgetting in the visuospatial sketchpad of humans and monkeys. Poster presented at the meeting of the American Psychological Society, Chicago, IL.

- Washburn, D. A. (1993, April). Comparative Investigations of Attention. Paper presented at the 85th meeting of the Southern Society for Philosophy and Psychology, New Orleans, LA.
- Washburn, D. A., & Rumbaugh, D. M. (1992, August). Training Rhesus Monkeys using the Computerized Test System. Paper presented at the XIV Congress of the International Primatological Society, Strasbourg, France.
- Schull, J., Smith, J. D., and Washburn, D. A. (1992, August). Uncertainty Monitoring in Rhesus Monkeys. Paper presented at the XIV Congress of the International Primatological Society, Strasbourg, France.
- Hopkins, W. D., Washburn, D. A., Berke, L., & Williams, M. (1992, August). Behavioral Asymmetries of Psychomotor Performance in Rhesus Monkeys (Macaca mulatta). Paper presented at the XIV Congress of the International Primatological Society, Strasbourg, France.
- Washburn, D. A. (1992, June). Cognitive Science with a Comparative Perspective: Resource Allocation by Monkeys and Humans. Poster presented to the annual meeting of the American Psychological Society, San Diego, CA.
- Washburn, D. A., & Rumbaugh, D. M. (1991, November). Joystick and Graphics Utilities for Studying Behavior. Paper presented to the annual meeting of the Society for Computers in Psychology, San Francisco, CA.
- Washburn, D. A. (1991, November). A Tool for Analyzing Response Sequences. Paper presented to the annual meeting of the Society for Computers in Psychology, San Francisco, CA.
- Washburn, D. A., & Rumbaugh, D. M. (1991, October). Environmental Enrichment and Performance Assessment for Ground- or Flight-Based Research with Primates. Poster presented to the annual meeting of the American Society for Gravitational and Space Biology, Washington, DC.
- Washburn, D. A., & Rumbaugh, D. M. (1991, October). Investigations of Rhesus Monkey (Macaca mulatta) Video-Task Performance: Evidence for Enrichment. Paper presented to the Annual meeting of the American Association for Laboratory Animal Science, Buffalo, NY.
- Washburn, D. A., Rumbaugh, D. M. (1991, June). Patterns of Psychomotor Responding by Humans and Monkeys (Macaca mulatta). Poster presented to the third annual meeting of the American Psychological Society, Washington, DC.
- Washburn, D. A. (1991, June). Comparative Models of Video Task Performance. Paper presented to the third annual meeting of the American Psychological Society, Washington, DC.
- Washburn, D. A., & Rumbaugh, D. M. (1991, April). The Language Research Center's Computerized Test System (LRC-CTS): New Vistas for Comparative Learning. Paper presented to the meeting of the Eastern Psychological Association, New York, NY.
- Washburn, D. A., Rumbaugh, D. M., Putney, R. T., & Hopkins, W. D. (August, 1990). Apparatus as milestones in the history of comparative psychology. Paper presented to the 98th annual convention of the American Psychological Association, Boston, MS.
- Rumbaugh, D. M., Washburn, D. A., Savage-Rumbaugh, E. S., Hopkins, W. D., & Richardson, W. K. (1990, July). The Language Research Center's Computerized Test System (LRC-CTS): Video-formatted tasks for comparative primate research. Paper presented at the 13th congress of the International

Primatological Society, Nagoya, Japan.

- Rumbaugh, D. M., Washburn, D. A., Savage-Rumbaugh, E. S., & Hopkins, W. D. (1990, July). Numeric skills of chimpanzees and rhesus monkeys. Paper presented at the 13th congress of the International Primatological Society, Nagoya, Japan.
- Washburn, D. A., Rumbaugh, D. M., & Hopkins, W. D. (1990, November). The enhancement of video-task automation and social factors upon cognition in monkeys and apes. Paper presented at the annual meeting of the American Psychological Society, Dallas, TX.
- Washburn, D. A., Astur, R. S., Hopkins, W. D., & Rumbaugh, D. M. (1990, April). The recognition of lateralized stimuli by humans, chimpanzees, and monkeys. Paper presented at the annual meeting of the Southeastern Psychological Association, Atlanta, GA.
- Rumbaugh, D. M., Washburn, D. A., Savage-Rumbaugh, E. S., & Hopkins, W. D. (1990, March). The Language Research Center's Computerized Test System (LRC-CTS): Video-formatted tasks for primates. Paper presented at the annual meeting of the Eastern Psychological Association, Philadelphia, PA.
- Rumbaugh, D. M., Hopkins, W. D., & Washburn, D. A. (1989, November). Judgments of relative numerosity by macaques (Macaca mulatta) in a video-task paradigm. Paper presented at the meeting of the Psychonomic Society, Atlanta, GA.
- Washburn, D. A., Rumbaugh, D. M., & Richardson, W. K. (1989, November). PC-compatible computer-generated stimuli for video-task testing. Paper presented at the annual meeting of the Society for Computers in Psychology, Atlanta, GA.
- Richardson, W. K., Washburn, D. A., Hopkins, W. D., Savage-Rumbaugh, E. S., & Rumbaugh, D. M. (1989, November). The NASA/LRC Computerized Test System. Paper presented at the annual meeting of the Society for Computers in Psychology, Atlanta, GA.
- Washburn, D. A., Hopkins, W. D., & Rumbaugh, D. M. (1989, August). Effects of task choice upon performance in macaques (Macaca mulatta). Poster presented at the meeting of the American Psychological Association, Atlanta, GA.
- Washburn, D. A., Hopkins, W. D., & Rumbaugh, D. M. (1989, March). Effects of competition upon video-task performance. Paper presented to the meeting of the Southeastern Psychological Association, Washington, D.C.
- Hopkins, D. A., Washburn, D. A., & Rumbaugh, D. M. (1989, March). Effects of stimulus movement upon learning and memory in macaques. Paper presented to the meeting of the Southeastern Psychological Association, Washington, D.C.
- Washburn, D. A., Hopkins, W. D., & Rumbaugh, D. M. (1988, October). Automation of learning set testing: The video-task paradigm. Paper presented at the annual meeting of the Society for Computers in Psychology, Chicago, IL.

Appendix B

A selective listing of significant research findings supported by NASA Grant NAG2-438 1987 - 1999

Research using the Psychomotor Test System (PTS) has challenged many of the preconceptions regarding rhesus macaques and their learning or cognitive skills. Experiments conducted as ground-based baseline studies have revealed capabilities or limitations in the monkeys' ability to learn, remember, attend, solve problems, and so forth that have influenced theories of cognitive human cognitive function -- as well as the design of flight hardware and protocols. A selective list of the substantive scientific yield from NAG2-438 must include the following.

Spaceflight:

1. Rhesus monkeys, ranging in age from about 2 years into the teens, can be trained quickly and efficiently to manipulate a joystick so as to respond to computer-generated stimuli.
2. These monkeys readily perform thousands of trials per day on tasks -- before flight, after flight, and during the restraint of ground-control tests.
3. Dozens of control and feasibility studies were conducted to determine the effects on performance of spaceflight-relevant conditions (e.g., noise, isolation, restraint, visual versus auditory reinforcement, physical configuration of environment, water consumption, and so forth).
4. Performance and productivity are adversely affected by surgical procedures that can follow flight or control conditions.
5. These disruptions in the number of trials completed, and the accuracy or speed with which these trials are performed, appear to be most pronounced following spaceflight (versus ground-control) conditions.
6. Changes in joystick-task performance correlate with, and may be diagnostic of, changes in health and well-being as assessed by subjective measures.
7. Analysis of videotaped behavior reveals that the monkeys appeared generally to be healthy but bored during spaceflight and ground-control tests. This observation, together with the intriguing changes in psychomotor performance observed on a preflight/postflight basis, suggests the importance of including PTS in-flight during future studies.
8. These changes in performance should correspond to changes in motor control, locomotion, and physiological measures that will be reported in detail by other investigators associated with Bion-11.

General:

1. With proper training, macaques can overcome conditions of stimulus-response spatial discontiguity (a condition that had previously and repeatedly been demonstrated to impair learning), response-reward discontiguity, and problems with planometric stimuli.
2. Like humans, rhesus monkeys show impaired performance (productivity, accuracy, response time) under conditions of social isolation. These effects appear to reflect changes in psychological well-being, rather than an absence of social facilitation effects.
3. Rhesus monkeys can "learn-to-learn" and become efficient one-trial learners (even when tested with automated apparatus).
4. Further, as a result of experience with PTS tasks, rhesus monkeys shift their object-discrimination performance from relatively simple stimulus-response associations to more advanced, rule-like forms of learning. These relational or mediational behaviors and positive transfer-of-learning skills are qualitative characteristics of learning and transfer that had heretofore been demonstrated only for humans and great apes.
5. Rhesus monkeys, like humans, will choose to work for rewards rather than to receive them freely. They will work on PTS tasks even when other favorite activities are available. The time spent on task-directed activity appears to replace relatively undesirable behaviors (e.g., overgrooming, stereotypy) in the animal's repertoire. In summary, study after study reveals the PTS to be unsurpassed as a tool for environmental enrichment and the support of nonhuman primate psychological well-being.
6. Like humans, rhesus monkeys are "super-learners" in that they learn more than they must simply to receive a reward. For example, the monkeys learned to respond to Arabic numerals in accordance to the number of pellets each numeral represented, even though the monkeys were reinforced whether or not they selected the numerals in proper sequence. These numeric symbols appear to represent their corresponding quantities, as is found with humans, and suggest that macaques may be capable of even more complex aspects of symbol learning and use (e.g., language, arithmetic).
7. These and similar data suggest that reinforcement is effective for maintaining behavior (i.e., to keep an animal responding), but that learning is a matter of learning to recognize latent patterns in the relations of stimuli and responses. Learning is not the simple strengthening of prior behaviors as a result of their consequences.
8. Neither monkeys nor humans appear covertly to rehearse visuospatial stimuli that must be remembered over short periods of time. Although both species are skilled at recognizing these stimuli later, there is no evidence for active processing of the to-be-remembered items during retention intervals.
9. Rhesus monkeys, like humans, monitor their levels of certainty and respond adaptively to

uncertainty when given the option to do so. This indicates metacognitive skills by rhesus monkeys that are qualitatively comparable, if quantitatively inferior, to humans and apes.

10. Like humans, rhesus monkeys manifest qualitatively different patterns of responding under conditions of joystick-task competition, compared to control conditions. That is, the monkeys respond as if they know that they are competing, and shift their response strategies to win. These data suggest that the effects of competition are akin to incentive effects (i.e., it is more reinforcing to win a pellet than to get the same pellet under noncompetitive circumstances), rather than due to presentation considerations or some artifact of the situation.

11. The perception of choices and control is an important hallmark of intelligence, and we demonstrated that rhesus monkeys can perceive the opportunity for control when it is available to them. Furthermore, their performance is reliably better on tasks of their choosing than on those same tasks when assigned to them under comparable conditions of variety, preference, and difficulty.

12. Rhesus monkeys, like humans, show reliable correlation between intelligence and processing speed (the speed with which even simple decisions are made). This reveals continuity in intelligence and its chronometric measurement across primate species. Curiously, though, rhesus monkeys have mental processing speeds much faster than do humans! Follow-up studies are ongoing to determine why, if "faster is smarter" humans are slower.

13. Rhesus monkeys show clear handedness for joystick manipulation and other fine-motor-control skills, whereas gross motor skills (e.g., reaching) generally fail to reveal strong hand preferences. Hand preferences can be disambiguated from hand skill with these animals, however. Whereas all monkeys tend to attain approximately equivalent levels of asymptotic performance on PTS tasks, right-handed monkeys learn reliably faster than left-handed monkeys. These patterns of handedness and hand-skill cannot be traced to artifacts of the test environment.

14. In studies to date, rhesus monkeys (unlike humans and language-trained chimpanzees) do not show strong and reliable asymmetries in left-hemisphere versus right-hemisphere function in the recognition of visuospatial stimuli. However, this absence of species-general patterns of functional cerebral specialization belies strong asymmetries for individual animals. Ongoing studies are examining the relation between the strength or direction of these hemispheric asymmetries with other aspects of neuro-cognitive performance.

15. Rhesus monkeys respond as "predictor-operators" in psychomotor tasks. That is, they attempt to predict where a moving target is going, and respond to a point that approximates optimal intersection with the moving stimulus. Although less accurate than humans at predicting target outcome, macaques do nonetheless have the capacity that had heretofore been argued to be unique to human performance.

16. Rhesus monkeys, like humans, can respond to stimuli that are obscured or invisible. That is,

they represent the unseen movements of targets, based on the prior trajectory of these stimuli, and respond appropriately on the basis of extrapolation and object permanence. These capabilities provide important benchmarks for comparing species differences to human developmental differences.

17. A variety of important attentional phenomena (e.g., Stroop effects, serial search and pop-out effects) have been observed for rhesus monkeys. These demonstrations support the continuity in cognitive processes across species (i.e., variables that influence human performance should--and do--similarly influence performance by macaques, and variables that fail to influence performance by humans should not affect performance by macaques). It is increasingly clear that monkeys do attend and process information, but that the degree of control that nonhuman primates have over cognition is relatively less than that which is characteristic of human adults and most children.

18. Tasks developed to train macaques or to assess the cognitive performance of nonhuman primates have been demonstrated to be effective for training children and youths with mental retardation or other developmental disabilities. These studies will continue to examine the use of PTS tasks and procedures for the education and assessment of toddlers, children and adults with attention deficit and hyperactivity disorder, and other special populations.